Hydrogeology for Underground Injection Control in Michigan:

Part 1

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Figure 2.2. Stratigraphic succession in Michigan. (From MDNR, 1964, Chart 1.)

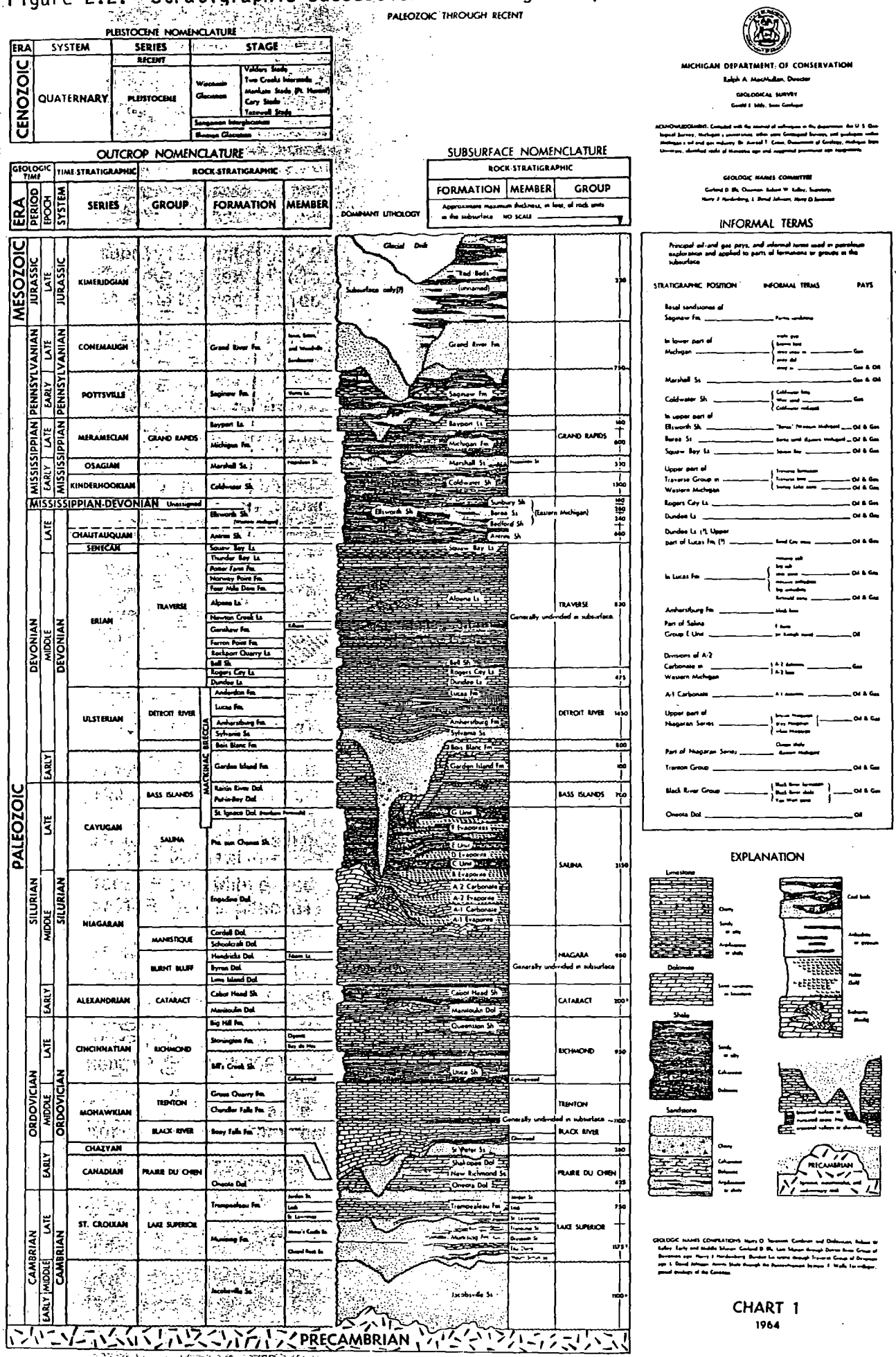
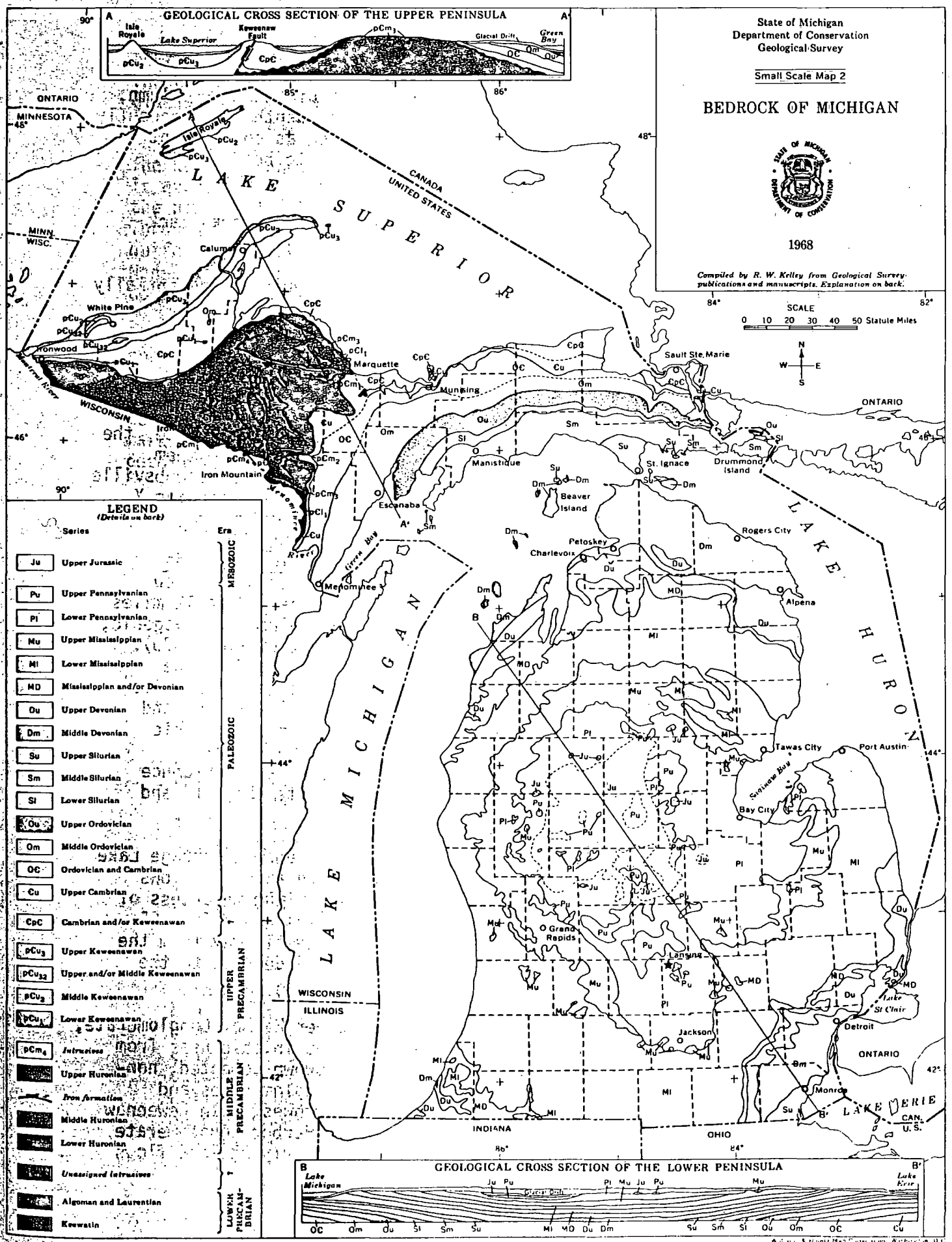


Figure 2.3. Geologic map of Michigan.



Characteristics as an Aquifer. Unknown.

Characteristics as a Confining Layer. Unknown. Discontinuous nature of the unit coupled with the presence of sandstone and dolomite do not recommend it as a confining layer.

Characteristics as an Injection Formation. Discontinuous nature of the Garden Island Formation suggests that it would be an inadequate injection formation.

Porosity and Permeability. Unknown.

MIDDLE DEVONIAN

Bois Blanc Formation

From its truncated margin at outcrop in the area of Mackinac Straits the Bois Blanc Formation increases to a maximum thickness of more than 600 feet in Arenac and Gladwin Counties (Cohee, et al., 1951) (fig. 2.30, pls. 5, 6 and 11). The basal 75 feet of the unit is dolomite with interbeds of chert and is overlain by about 200-300 feet of very cherty dolomite and limestone. The upper 75 feet of the unit is fossiliferous limestone.

Characteristics as an Aquifer. The Bois Blanc is not used as an aquifer. In and near the outcrop area it has been leached and could be used as a source of water in the area near the Straits of Mackinac. Proximity of the outcrop area to Lake Michigan and the availability of water in the glacial aquifer have made the use of this aquifer unnecessary to date.

Characteristics as a Confining Layer. Away from the outcrop area the Bois Blanc is very dense and should form a barrier to the movement of fluids. The cherty dolomites are likely to be quite brittle and may have some fracture porosity and permeability. The unit was involved in the subsidence that produced the Mackinac Breccia, and it is very likely highly fractured in the area where this process has occurred (pl. 18).

Characteristics as an Injection Formation. The Bois Blanc Formation is unsuitable for use as an injection formation.

Porosity. Very low.

Permeability. Unknown. Fracture porosity may be present.

Oil and Gas Potential. Low.

Sylvania Sandstone

The Sylvania Sandstone is composed of well-rounded and sorted, fine (0.18 mm) to medium (0.40 mm) grained quartz grains notably free of clay. The sandstone overlies dolomites of the Bass Islands Group with distinct

disconformity along the northern margin of its development in northern Ohio and southeastern Michigan. To the north where the Bois Blanc Formation is the basal unit of the Middle Devonian, the Sylvania Sandstone interfingers with cherty carbonates. Contact with the overlying Detroit River beds is transitional from sandstone to dolomitic sandstone to sandy dolomite to dolomite. To the northwest in Wexford, Grand Traverse, Missaukee and Kalkaska Counties, the Sylvania contains thick deposits of tripolitic (de-vitrified) chert with amber dolomite rhombohedrons. The Sylvania outcrops in southeastern Michigan and ranges in thickness from a zero edge in southern Michigan to more than 500 feet in the central part of the Michigan Basin (fig. 2.30).

Characteristics as an Aquifer. In and near the outcrop area where it has been flushed the Sylvania Sandstone is a good aquifer, but because it is overlain by glacial lake beds, composed of silt and clay, water in it commonly contains methane and hydrogen sulfide.

Characteristics as a Confining Layer. The Sylvania is far too permeable to be a confining layer.

Characteristics as an Injection Formation. In areas where the Sylvania is overlain by the anhydrite of the Detroit River, it is a potential injection formation and has been used for both chemical and brine disposal. Care should be taken to avoid areas near the outcrop as the overlying carbonate section may have fracture permeability.

Porosity. High effective porosity exists away from the upper transition with the Detroit River and southwest of the area where the Sylvania and Bois Blanc interfinger.

Permeability. Permeability is very high in those portions of the unit that are free of carbonate and chert cement (see above).

Potential for Oil, Gas and Brine Production. No oil or gas fields have been developed in the Sylvania. It is used extensively as a source of brine especially in the vicinity of Midland County.

Amherstburg

The Amherstburg is a dark brown to black, carbonaceous limestone throughout most of the basin, but around the southern and western margins of the Southern Peninsula it has been dolomitized. The informal name "Black Limestone" has been in use for many years as a driller's term. The lithology is very distinctive in the central-basin area, and was used as a marker at which to bottom exploratory tests into the Richfield zone of the Detroit River. The unit is poorly bedded, dense, and ranges in thickness from a zero edge in southwestern Michigan to more than 300 feet in the area of Saginaw Bay (fig. 2.31).

Characteristics as an Aquifer. The Amherstburg is not an aquifer.

Characteristics as a Confining Layer. Except where dolomitized, the Amherstburg is an aquiclude and could be used as a confining layer, in the central portion of the Michigan Basin.

Porosity. The effective porosity of the Amherstburg is low where it is dolomite and very low where it is limestone.

Permeability. The Amherstburg has very low permeability where it is dolomite and is virtually impermeable in those areas where it is a limestone.

Oil and Gas Potential. Very low.

Filer Sandstone Member

The Filer Sandstone is best developed along the western margin of the Southern Peninsula in the area of Manistee. The Filer is a fine to medium grained, quartz sandstone that appears to have been deposited as coastal dunes. Local lenticular sandstone bodies in the central part of the basin appear to be roughly correlative with this unit, and one such unit has been named the Freer Sandstone after a well that penetrated it.

Characteristics as an Aquifer. The Filer Sandstone has excellent aquifer characteristics, but it contains brine.

Characteristics as a Confining Layer. The Filer is far too porous and permeable to be used as a confining layer.

Characteristics as an Injection Formation. The Filer has excellent injection formation characteristics and is used as an injection formation in Michigan.

Porosity. The formation has up to 25 percent effective porosity.

Permeability. Very high.

Oil, Gas and Brine Potential. The Filer has been explored for oil and gas, but to date no sustained production has been developed. The Freer Sandstone had a "one-well" field developed in it. The Filer is a source of brine in the Manistee area.

Detroit River

Although the Bois Blanc Formation, Sylvania Sandstone, Amherstburg (Black Limestone), Lucas and Anderdon Formations have been included in the Detroit River Group, general practice is to call that portion of the column between the Amherstburg (Black Limestone) and the Dundee Limestone the "Detroit River," although it has been named the Lucas Formation. This suite of rocks is quite complex and contains a wide variety of lithologies including sandstone, limestone, dolomite, anhydrite (or gypsum) and halite (figs. to). The Basal unit of the "Detroit River" is the "Richfield zone" or more properly the Richfield Member.

Richfield Zone

The Richfield zone is a sequence of interbedded limestone, dolomite, and anhydrite with minor amounts of sand in the central portion of the basin and a relatively thick sand body, the Filer Sandstone, along the western margin of the Lower Peninsula (fig. 2.32). The limestone beds are dense micrites and contrast with the dolomites which are lighter in color and more permeable. The anhydrite beds have mosaic textures and generally overlie the dolomitized units.

Characteristics as an Aquifer. The Richfield zone is not an aquifer.

Characteristics as a Confining Layer. The anhydrites of the Richfield zone are excellent confining layers. The fact that several of the dolomite zones produce oil attests to the impervious nature of the interbedded anhydrites.

Characteristics as an Injection Formation. The Richfield contains too little permeable rock to be an injection formation.

Porosity. The dolomite zones in the Richfield are slightly porous, but the limestones and anhydrite beds essentially lack porosity.

Permeability. The limestone and anhydrite beds are virtually impermeable. The dolomite units have permeabilities that range from 4.0 to 6.5 milli-darcys.

Oil and Gas Potential. The Richfield has produced oil and gas from several fields in Michigan since the early 1940's.

Massive Anhydrite

The driller's term "Massive Anhydrite" has been traditionally applied to a thick (75-100 feet) anhydrite bed that overlies the Richfield Zone (fig. 2.33). The unit is widespread in the central portions of the basin and thins toward the basin margins. It is best developed in the north-central part of the Southern Peninsula.

Characteristics as an Aquifer. The Massive Anhydrite is not an aquifer.

Characteristics as a Confining Layer. The Massive Anhydrite is essentially impermeable and an excellent confining unit.

Characteristics as an Injection Formation. None.

Porosity. Extremely low.

Permeability. Extremely low to essentially impermeable.

Oil and Gas Potential. None.

western Southern Peninsula from Cadillac south into Indiana. Throughout the eastern margin of this area the anhydrite is underlain by a porous and permeable dolomite generally referred to as the "Reed City Zone". Gardner (1974) suggested that the Reed City dolomite and anhydrite are the western equivalents of the Dundee Limestone, and that they represent the westward movement of the evaporite forming conditions that existed in the Michigan Basin during deposition of the Detroit River. According to this view the Dundee is conformable with the underlying Detroit River.

Characteristics as an Aquifer. Throughout its extent in Michigan, the Reed City dolomite is filled with brine and/or hydrocarbons. The anhydrite is too impermeable to contain significant amounts of fluid.

Characteristics as a Confining Layer. The Reed City dolomite is too permeable to be a confining layer, but the overlying Reed City anhydrite is an excellent aquiclude.

Characteristics as an Injection Formation. Where the Reed City dolomite does not contain commercial quantities of hydrocarbons, it could serve as an injection formation.

Porosity. The Reed City dolomite is porous to very porous. The Reed City anhydrite essentially lacks effective porosity.

Permeability. The Reed City dolomite is permeable to very permeable. The Reed City anhydrite is essentially impermeable.

Oil and Gas Potential. The Reed City dolomite has produced significant quantities of oil and gas in the western part of the Southern Peninsula.

Dundee Limestone

The Dundee of driller's usage has been subdivided into the Rogers City and Dundee Limestones (Ehlers, 1945; Cohee & Underwood, 1945; Ehlers, et al., 1959; Gardner, 1974). Because the two units are generally undivided by the oil industry they will be discussed here as a single unit, the Dundee Limestone.

The Dundee is a fossiliferous limestone that is locally dolomitized (figs. 2.36 and 2.37). It ranges in thickness from about 150 feet in the western half of the Southern Peninsula to more than 350 feet in the east-central portion of the Michigan Basin. It is locally highly dolomitized, especially over anticlines in the central Michigan Basin.

Characteristics as an Aquifer. The Dundee Limestone is an aquifer in the northern portion of the Southern Peninsula and in its outcrop planes and solutionally enlarged joints. Because the water is present in "selective" porous and permeable zones associated with fractures and bedding planes it is susceptible to pollution. In the central part of the basin the Dundee contains brine and hydrocarbons.

Characteristics as a Confining Layer. In the eastern third of the Lower Peninsula, the Dundee is dominantly limestone and very slowly permeable. In this area the only limitations to its use as a confining layer is the presence of fractures.

Characteristics as an Injection Formation. In areas where the Dundee has been dolomitized, it could be and is used as an injection formation for chemicals and brine.

Porosity. In areas where the Dundee is limestone, it has very low effective porosity; however, in areas where the Dundee has been dolomitized it is very porous.

Permeability. Where the Dundee is limestone it is very slowly permeable but dolomitized zones are highly permeable.

Oil and Gas Potential. The Dundee has been a prolific oil and gas producer and is a prime target for oil and gas in the central Michigan Basin.

Traverse Group

The Traverse is a thick (100'-800') sequence of alternating shales and limestones in the northeastern two-thirds of the Southern Peninsula (figs. 2.38 to 2.40). In the "Thumb" area shales comprise more than 80 percent of the Traverse Group. In contrast, shale makes up less than 20 percent of the unit in southwestern Michigan. The Traverse has been subdivided in the Alpena and Traverse City areas and, in general, each of the alternating shales and limestone units has been assigned a formation name. To the southwest, the shales thin and the distinctive character of each limestone unit becomes progressively more obscure until it is impossible to distinguish units within the Traverse Group. Even the Traverse-Dundee contact is difficult to discern.

The Traverse crops out and subcrops beneath the glacial drift around the northern margin of the Southern Peninsula and in southeastern Michigan. In the northern outcrop band, the presence of shale or limestone at the surface is an important controlling factor in the potential of the Traverse as an aquifer. Where shales are at the surface, as in the area of Bell Shale (basal Traverse Group), bedrock is not generally used as an aquifer. In contrast, outcrop bands of the limestone units form bedrock aquifers.

Characteristics as an Aquifer. The shales in the Traverse Group are not aquifers. The limestone units are "karst" aquifers, and may supply large volumes of water locally. The cavernous nature of these units makes them extremely vulnerable to contamination.

Characteristics as a Confining Layer. The shales in the Traverse Group, especially the Bell Shale, are excellent confining layers. To the southwest, the shales thin and are less adequate barriers to the movement of fluids. The numerous oil and gas fields in the underlying Dundee attest to the impermeable nature of the Bell Shale. The limestone units should not be regarded as aquicludes, especially in and near the outcrop areas.

Characteristics as an Injection Formation. The Traverse "Limestone" is productive of oil and gas in central and western parts of the Michigan Basin. The porous zones that produce hydrocarbons and brine can be, and are used for injection of fluids, but hydrocarbon potential should be considered when siting Traverse disposal wells.

Porosity. The shales in the Traverse Group generally have very low effective porosity. The limestone units are generally relatively impermeable, but have local porous zones. The uppermost limestone unit in the Traverse, generally referred to as the "Traverse Limestone," or in some reports as the "Squaw Bay," is porous over wide areas of the central and western Michigan Basin.

Permeability. The shales of the Traverse Group are generally impermeable, and the limestones are only locally so. The top few feet of the uppermost Traverse Limestone unit is generally permeable in the central and western parts of the basin.

Oil and Gas Potential. The Traverse Limestone unit produces oil, gas and brine throughout the central and western portions of the basin.

Antrim Shale

The Antrim Shale is a hard, dark gray to black or dark brown, pyritiferous shale that locally contains abundant silt. It ranges in thickness from 120 feet to more than 600 feet (figs. 2.41 and 2.42). In southern Michigan, the basal member of the Antrim is a dark gray dolomite that correlates with the Blocher Member of the New Albany Shale in Indiana. In Michigan this member is referred to as the Traverse Formation. The Antrim Shale is part of the greater "eastern black shale" that includes (1) the New Albany in Indiana; (2) the Ohio Shale in Ohio; and (3) the Chattanoga Shale in Kentucky.

Characteristics as an Aquifer. The Antrim Shale is generally too impermeable to be an aquifer. The low permeability coupled with the presence of abundant pyrite and marcasite generally restrict its use.

Characteristics as a Confining Layer. The Antrim is an excellent confining layer. It forms the seal over most of the Traverse oil fields in Michigan.

Characteristics as an Injection Formation. The Antrim is too impermeable to be used as an injection formation.

Porosity. The effective permeability of the Bedford Shale is very low.

Permeability. The Bedford Shale has very low permeability.

Oil and Gas Potential. None.

Berea Sandstone

The Berea Sandstone consists of a moderately fine-grained sandstone that grades upward and downward into shaly, dolomitic sandstone. The Berea is more than 100 feet thick on the east side of the Southern Peninsula and thins progressively to the west. In the central part of the basin, the Berea and Bedford are difficult to distinguish and farther west, the Berea grades into the upper Ellsworth Shale. In the central part of the Michigan Basin the Berea is as much as 1800 feet below sea level (figs. 2.45 and 2.46).

Characteristics as an Aquifer. In eastern Michigan, in and near its outcrop belt, the Berea has good aquifer characteristics.

Characteristics as a Confining Layer. The Berea is too permeable to serve as a confining layer.

Characteristics as an Injection Formation. In and near the outcrop, the Berea is an aquifer and should not be used as an injection formation. In the east-central part of the state it is capable of receiving fluids, but produces hydrocarbons and is relatively shallow.

Porosity. The middle portion of the Berea has good porosity, but the upper and lower parts of the unit are shaly and have a low effective porosity.

Permeability. The middle unit of the Berea is fairly permeable, but the upper and lower zones have a much diminished permeability because of an increased shale content.

Oil and Gas Potential. Several fields in eastern Michigan produce oil and gas from the Berea; however it is not considered to be a prime exploration target.

Sunbury Shale

The Sunbury is a dark gray to black or brown, bituminous, pyritic shale, similar in many respects to the Antrim Shale. It ranges in thickness from 0 feet in parts of the western Southern Peninsula to as much as 140 feet on the eastern side of the state (figs. 2.47 and 2.48). The formation thins from east to west and is the facies equivalent of the upper Ellsworth. The Sunbury reaches a maximum depth of about 1800 below sea level in the center of the Michigan Basin.

Regional Water Resources

REGION I: SOUTHEAST MICHIGAN

Introduction

The area designated as Region I, Southeast Michigan, includes ten counties within two state planning and development regions (fig.3.10). Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties are members of the Southeast Michigan Council of Governments, centered in Detroit. The three remaining counties, Genesee, Lapeer, and Shiawassee, comprise the GLS Region 5 Planning and Development Commission, which has its offices in Flint.

Population

In 1980 the population of Region I, Southeast Michigan, was 5,273,758, or 57 percent of Michigan's total population (table 3.7). The region experienced a 0.4 percent decrease in population from 1970, and is the only region in Michigan to experience a population loss. The decrease represents an outflow of 23,275 people from the region since 1970. Nine of the region's 10 counties experienced population increases during this period, the greatest, 70.1 percent, occurring in Livingston County. Wayne County experienced the only decrease in the region but this decrease of 12.5 percent was greater than the total population increase in the other nine counties.

Eight of the ten most highly populated cities in Michigan are located in this region. Detroit, the largest city in Michigan with a population of 1,203,399, accounts for 22.8 percent of the regional population and 13.0 of the state population. The four most populous counties in Michigan are also located in this region, and include Wayne, Oakland, Macomb, and Genesee Counties. Wayne and Oakland Counties far exceed all other counties in population with 2,337,240 and 1,011,793 inhabitants respectively. The two counties combined contained 36.1 percent of the total population in Michigan, 25.2 percent of 10.9 percent respectively.

Industry and Agriculture

The retail and wholesale trade values for Southeast Michigan are highest in Wayne and Oakland Counties. Detroit, in Wayne County, is the oldest city in the Midwest and a major international lake port. The Detroit Metropolitan area industries produce 80 percent of all cars made in the U.S. Approximately 46 percent of earnings in Wayne County are from manufacturing industries, 36 percent in Oakland County.

The automobile industry is the major source of employment in Macomb County. Manufacturing industries employ 54.5 percent of the county population. Similarily, Genesee County's industry is primarily automotive with 70 percent of the manufacturing jobs, or approximately 50 percent of the county's population, employed by the automobile industry. Also, many people commute from counties such as Shiawassee County which has 43.5 percent of its employed population engaged in manufacturing.

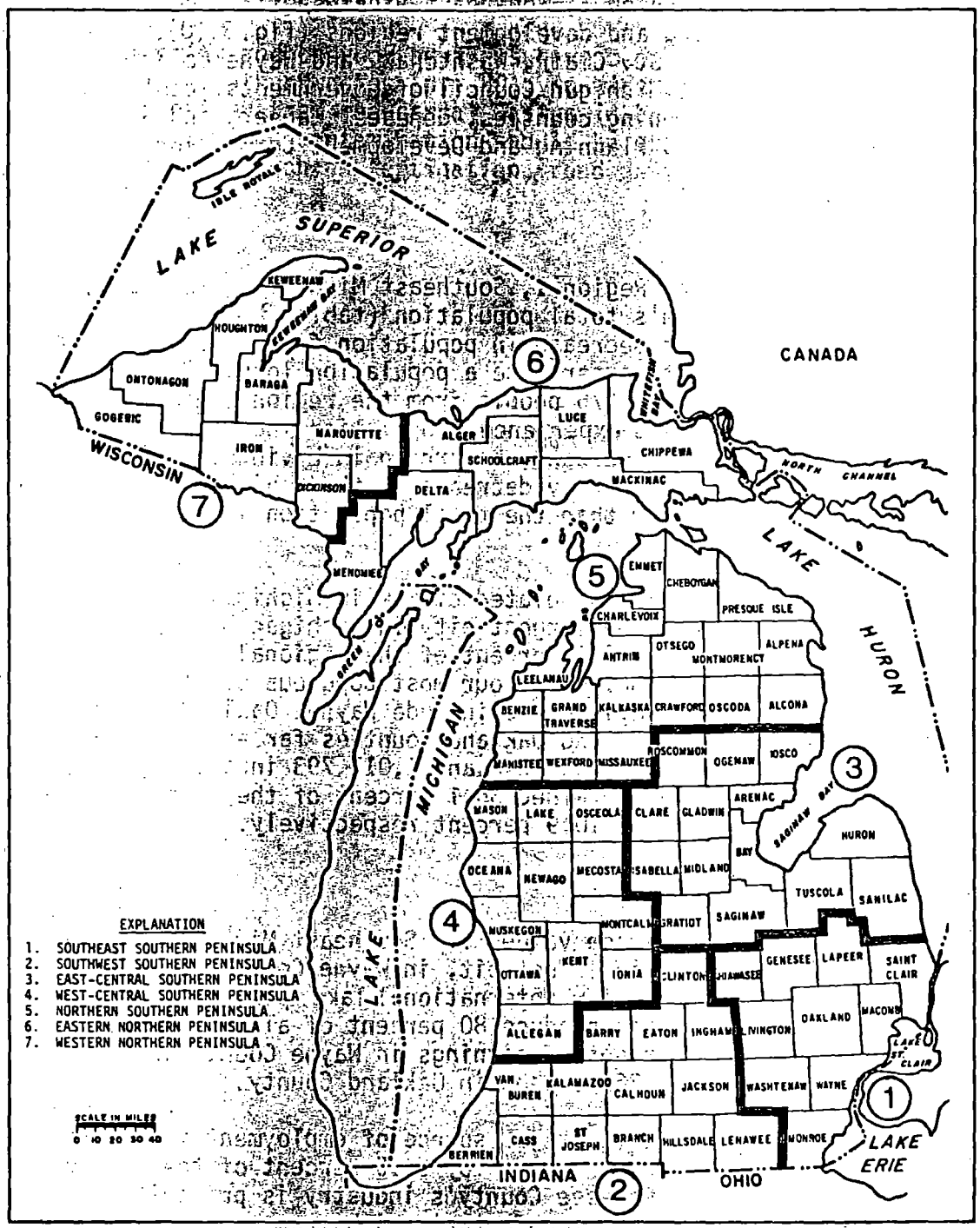


Figure 3.7. Water resource report regions.

TABLE 3.10 - POPULATION OF COUNTIES AND MAJOR MUNICIPALITIES IN REGION 1, SOUTHEAST MICHIGAN (1970-1980)
(Source: U.S. Bureau of the Census, 1980 Census of Population and Housing, Advance Report, PHC80-V-24)

Municipality	1970	1980	Percent Change (1970 to 1980)
REGION TOTAL	5,297,033	5,273,758	- 0.4
Genesee County			
Genesee County	445,589	450,449	1.1
Flint*	193,317	159,611	-17.4
Burton	32,540	29,976	- 7.9
Fenton	8,284	8,098	2.2
Flushing	7,190	8,624	19.9
Davison	5,259	6,087	15.7
Grand Blanc	5,132	6,848	33.4
Swartz Creek	4,928	5,013	1.7
Mount Morris	3,778	3,246	-14.1
Clio	2,357	2,669	13.2
Montrose	1,789	1,706	4.6
Linden	1,546	2,174	40.6
Goodrich	774	795	2.7
Otisville	724	682	- 5.8
Lapeer County			
Lapeer County	52,361	70,038	33.8
Lapeer*	6,314	6,225	- 1.4
Imlay City	1,980	2,495	26.0
Almont	1,634	1,857	13.6
Columbiaville	935	953	1.9
North Branch	932	896	- 3.9
Dryden	654	650	- 0.6
Otter Lake	549	442	-19.5
Clifford	472	406	-14.0
Metamora	468	552	17.9

Municipality	1970	1980	Percent Change (1970 to 1980)
Oakland County			
Oakland County	907,871	1,011,793	11.4
Royal Oak	86,238	70,893	-17.8
Pontiac*	85,279	76,715	-10.0
Southfield	69,285	75,568	9.1
Farmington Hills	50,047	58,056	16.0
Troy	39,419	67,102	70.2
Madison Heights	38,599	35,375	- 8.4
Oak Park	36,762	31,537	-14.2
Ferndale	30,850	26,227	-15.0
Birmingham	26,170	21,689	-17.1
Hazel Park	23,784	20,914	-12.1
Berkley	21,879	18,637	-14.8
Clawson	17,617	15,103	-14.3
Beverly Hills	13,598	11,598	-14.7
Farmington	10,329	11,022	6.7
Novi	9,668	22,525	133.0
Huntington Woods	8,536	6,937	-18.7
Rochester	7,054	7,203	2.1
Milford	4,699	5,041	7.3
Lathrup Village	4,676	4,639	- 0.8
Holly	4,355	4,874	11.9
Wolverine Lake	4,301	4,968	15.5
Pleasant Ridge	3,989	3,217	-19.4
Walled Lake	3,759	4,748	26.3
Bloomfield Hills	3,672	3,985	8.5
Franklin	3,311	2,864	-13.5
Keego Harbor	3,092	3,083	- 0.3
Lake Orion	2,921	2,907	- 0.5
South Lyon	2,675	5,214	94.9
Oxford	2,536	2,746	8.3
St. Clair County			
St. Clair County	120,175	138,802	15.5
Port Huron*	35,794	33,981	- 5.1
Marysville	5,610	7,345	30.9
St. Clair	4,770	4,780	0.2
Marine City	4,567	4,414	- 3.4
Algonac	3,684	4,412	19.8
Yale	1,505	1,814	20.5
Capac	1,279	1,377	7.7

Other sources of income are services and retail industries, each of which employs about 15-22 percent of the working force in most counties. Oakland County has many lakes intensely used year-round for recreation which contributes to the high percentage of people employed in services and retail industries, 23.5 percent and 23.0 percent respectively. Approximately 3.8 percent (197,700 acres) of the land in Southeast Michigan is identified as Public Recreation Lands, including 156,078 acres owned by local governments.

As of 1979, approximately 85 percent of all petroleum produced in Southeast Michigan was from wells in St. Clair County. Livingston County had the highest relative employment by the mining industry, 0.9 percent of the County population. Government is also a major employer with centers in Washtenaw County providing 27.8 percent of the income of employed county residents, and Lapeer County providing 34.5 percent.

Land used for agricultural purposes in Southeast Michigan comprises 1,830,075 acres, about 44 percent of the total area of the region, 4,145,280 acres. Farm industry accounts for 7.9 percent of the total county income in Lapeer County, the highest in the region. Washtenaw, Shiawassee and Monroe Counties contain 42 percent of the agricultural land in the region, with nearly two-thirds in Shiawassee and Monroe.

Population and Water Well Distribution

Within Region I, the majority of the areas of greatest water-well density are associated with the cities of Flint, Pontiac, and the northwest suburbs of Detroit (pl. 20). These areas include large portions of Genesee and Oakland Counties, and southeastern Livingston County. Region I ranks first in the state with respect to the number of water wells per county, and includes five of the leading six counties: Oakland, Genesee, Livingston, Monroe, and Washtenaw. The region has an estimated 61,104 water wells, 28.1 percent of the state total. Oakland County has more water wells than any other county in Michigan with 16,942 wells, 7.8 percent of the state total. The township with the greatest well density in Region I, and in the State of Michigan is Grand Blanc Township of Genesee County with a total of 2141 wells and an average of over 59 wells per square mile. The area of lowest well density is the Detroit Metro area, including most of Wayne County and sections of Oakland and Macomb Counties, where the average density of wells is less than eight wells per township.

Region I ranks first among the regions of Michigan in total population with 5,273,758 people, or 57.0 percent of the total state population (pl. 2). The region includes the four most populous counties in the state: Wayne, Oakland, Macomb, and Genesee. Wayne and Oakland Counties far exceed all other counties in population with 2,377,240 and 1,011,793 residents respectively. The two counties combined comprise 36.1 percent of the total state population, 25.2 percent and 10.9 percent respectively. With the exception of Wayne County which receives the majority of its water from surface supplies, the number of water wells correlates closely with population.

GEOLOGY

Topography

The preglacial topography of Southeast Michigan has strongly influenced the present topography (pl. 13). Prior to glaciation, the landscape comprised part of two physiographic regions, the Thumb Upland in the northwest and the Erie-Huron Lowland in the southeast. The Upper Devonian Berea Sandstone forms the approximate boundary between the two regions (pl. 6). The Thumb Upland is underlain by formations younger than the Berea, primarily the Coldwater Shale and Marshall Sandstone, and the Erie-Huron Lowland is developed on formations older than the Berea (Mozola, 1953). Glacial deposition has preserved, or even exaggerated the upland/lowland relationship. Thus Southeast Michigan has two distinct topographies, a nearly featureless plain in the southeast, and an elevated, hilly area in the northwest with plains also present in the extreme northwestern portion of the region.

The southeastern and northern plains formerly constituted the beds of a succession of preglacial lakes formed when glacial ice occupied the basins of the modern Great Lakes. The level of the highest beach line is about 850 feet above mean sea level (MSL) near Imlay City in Lapeer County, decreasing to about 800 feet at the Michigan-Ohio border. All of the area lying below these elevations consists of lake-bed plains, which slope gently southeastward and comprise the land surface of Monroe County, nearly all of Wayne, Macomb, and St. Clair Counties, southeastern Oakland County, northern Shiawassee, and northwestern Genesee Counties. The flatness of these plains is interrupted only by major drainage channels, faint ridges marking the beaches of former glacial lakes, and subdued, water-laid moraines.

In contrast to the nearby flat topography of the lake plains, the topography of the northwestern part of the region consists of belts of morainal hills and pitted outwash plains. In Genesee and Shiawassee Counties the moraines are superimposed, increasing the local relief. The topography in this area has greater relief and is characterized by knobs, knolls and pitted outwash plains.

The general elevation of the moraines increases to the northeast, reaching a maximum of 1221 feet (MSL) at Pine Knob in Independence Township, Oakland County. Several morainic knolls in Oakland, Livingston, Macomb and Washtenaw Counties stand at elevations of more than 1100 feet. Those counties which span both lake-bed plains and morainal regions exhibit the greatest relief with Oakland County having a maximum relief of 630 feet and Macomb County 578 feet of relief. In contrast, Monroe County lies entirely within the lake plain and has only about 160 feet of relief. The regional slope of the land surface in Southeast Michigan is southeast and northwest, away from the elevated morainal trend. Lake Erie, with an average surface elevation of 568.6 feet represents the lowest point in the area. Thus, maximum relief in Southeast Michigan is about 650 feet.

Glacial movement has played a prominent role in shaping the present landscape of Michigan and developing its most important aquifer system. During the Pleistocene Epoch, four major glacial advances probably crossed the state, but only the last, the Wisconsinan, left positively identified significant deposits (See Section II, Glacial Geology). The nature of these glacial deposits as related to aquifer systems is briefly summarized below.

Moraines

Moraines are ridges composed of glacial till material, a heterogeneous mixture of clay, sand, and bounders in various proportions. Most moraines originate at the stabilized front of an active glacier where large quantities of rock debris melt out of the ice and are deposited in ridges parallel to the ice front. The proportions of clay in the morainal sediments determines the aquifer characteristics.

Till Plains

Till plains are usually developed between end moraines. These gently rolling areas are underlain by till, referred to as ground moraine. The unsorted nature of glacial till results in low permeability and moderate porosity. These deposits are therefore generally incapable of yielding large volumes of water except when from local interbedded sand lenses, which may provide an adequate water supply to meet domestic needs.

Lake Plains

Lake beds (lacustrine) are deposits of ancestral lakes. They are typically composed of clay and silt and may be several tens of feet thick with low relief. Lacustrine sediments have low permeability and porosity and do not yield large quantities of water. Lake beds may locally contain sands, and are capable of meeting local water needs.

Outwash Plains

Outwash plains are formed from sediment deposited from glacial melt-waters. Outwash deposits are generally composed of well-sorted sands and gravels, and have high porosity and permeability. The coarsest sediments are generally deposited near the ice front with finer sands and silts deposited further from the ice front. The deposits generally constitute excellent aquifers.

Hydraulic Characteristics

Information on the hydrogeology of regions was acquired principally from engineering reports, well records, regional and county groundwater studies, and miscellaneous reports and personal communications with the Michigan Geological Survey and the United States Geological Survey. Aquifer characteristics most commonly available were well capacity, specific capacity, transmissivity and coefficient of storage.

These four hydraulic characteristics reflect the performance of the aquifer for each location and well. Well capacity, which is a measure of the well yield in gallons per minute (gpm), is the most commonly reported hydraulic characteristic. The greater the well capacity, the greater the production potential of the aquifer.

The specific capacity of a well is the well capacity, or yield, per unit of drawdown, usually expressed as gallons per minute per foot of drawdown (gpm/ft). The specific capacity reflects the aquifer's ability to recharge the well and normally the higher the specific capacity, the smaller the drawdown. Conversely, a low specific capacity is typically related to a larger drawdown. Specific capacities greater than 100 gpm/ft represent good aquifers for irrigation and municipal systems. Specific capacities of 0.1 to 1.0 represent fair to good aquifers for domestic purposes.

Transmissivity is defined as the rate of flow of water at the prevailing temperature through a vertical strip of aquifer one unit wide, extending the full saturated thickness of the aquifer, under a unit hydraulic gradient. Transmissivity data are presented in gallons per day per foot (gpd/ft). Transmissivities greater than 100,000 gpd/ft represent good aquifers for irrigation and municipal systems. Transmissivities of 1000 gpd/ft are adequate for domestic supplies.

The coefficient of storage, or storativity, of an aquifer is defined as the volume of water which an aquifer releases from, or takes into, storage per unit surface area of aquifer per unit decline or rise of head. Storativity is dimensionless, and for unconfined aquifers, normally ranges from 0.02 to 0.30. Storativity for confined aquifers normally ranges from 5.0^{-3} (0.005) to 5.0^{-5} (0.00005).

Hydraulic Characteristics Of Glacial Drift Aquifers

Data on the hydraulic characteristics of 1265 glacial drift wells were available from 152 locations within Region 1, (table 3.12). Oakland County had information for the most locations (37) and Washtenaw County had information for the greatest number of wells (773). Monroe County had information on the fewest glacial drift wells (4). Well depths in the region ranged from 24 feet in Lapeer County to 335 feet in Washtenaw County.

Nine values (4 percent) for well capacity were available for naturally flowing wells. Well capacity for flowing wells ranged from 3 gpm in Washtenaw County to 75 gpm in Monroe County. The well capacity of non-flowing wells ranged from 1 gpm in St. Clair County to 5000 gpm in Monroe County. For additional information see Table 3.12.

Specific capacity values for Region I ranged from 0.01 gpm/ft in St. Clair County to 600 gpm/ft in Washtenaw County. Genesee County was the only county that lacked specific capacity data.

Transmissivity values for the region ranged from 6450 gpd/ft to 500,000 gpd/ft in Oakland County. The coefficient of storage ranged from 3.4×10^{-7} (0.00000034) in Livingston County to 3.04 in Oakland County.

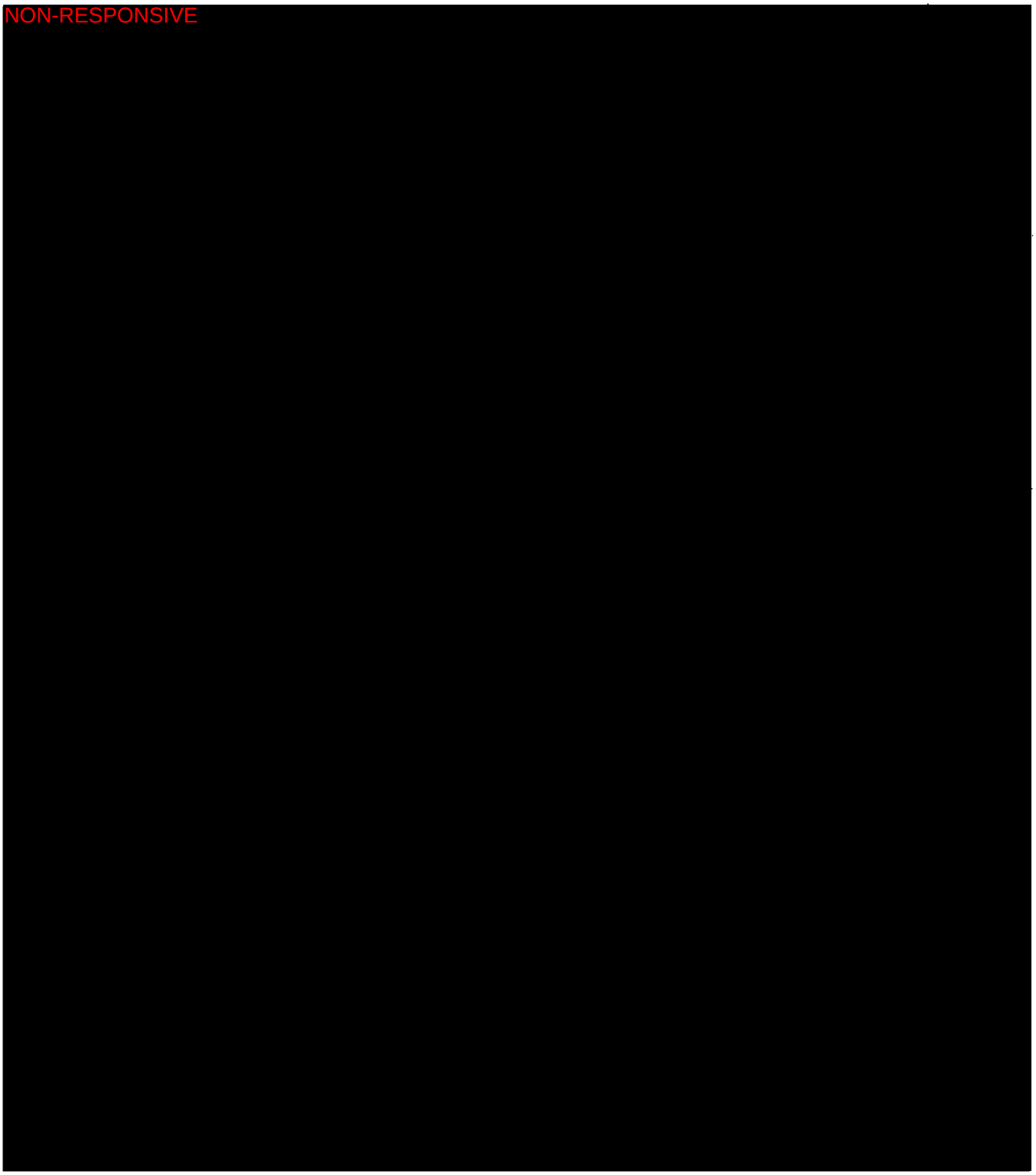
Water Quality In The Glacial Drift Aquifer

Water quality data for the glacial drift aquifer was available from the Michigan Department of Public Health for all the counties in Region 1 except Monroe and Wayne. The region included 96 reporting Community Public Water Supply Systems in 8 counties for which 363 water samples were analyzed from 189 wells in the glacial drift aquifer. Oakland County had the most abundant water quality data with 193 water samples analyzed from 104 wells in 58 water systems. Lapeer County had data for only 3 water samples from 3 wells in 1 water system. Table 3.13 presents data on 7 water quality parameters included in the EPA Interim Primary Drinking Water Standards. Range and mean were calculated for each parameter and standard deviation was calculated for counties with 30 or more water samples.

The parameters nitrate, fluoride, chloride, iron, and sulfate are shown on Plate 23, Quality of Water from Community Public Wells. These data represent Community Public Supply Systems only. Plate 25 shows total dissolved solids and specific conductance for Community Public Supply Systems and private wells.

None of the samples analyzed from Region 1 contained nitrate in excess of the primary maximum contaminant level (primary MCL). Only one water sample (< 1 percent) contained fluoride in excess of the primary MCL. The mean fluoride concentration for Region 1 was 0.47 mg/l, ranging from 0.0 mg/l to 2.60 mg/l. Fourteen water samples (4 percent) from 5 counties contained chloride in excess of the secondary maximum contaminant level (secondary MCL). The mean chloride concentration for

TABLE 3.12 - HYDRAULIC CHARACTERISTICS OF THE GLACIAL DRIFT AQUIFER SYSTEM, REGION 1 (SOUTHEAST MICHIGAN).



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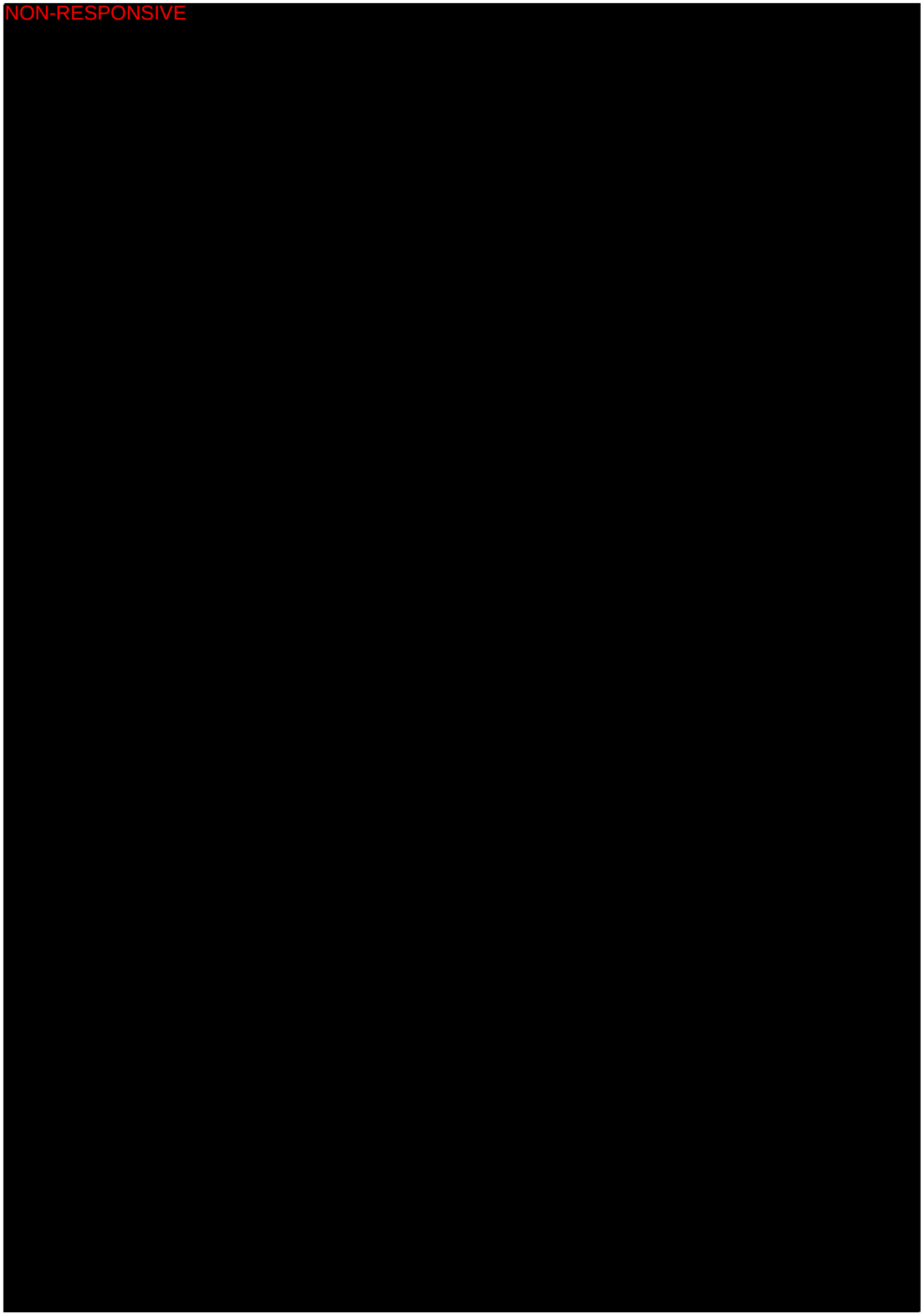

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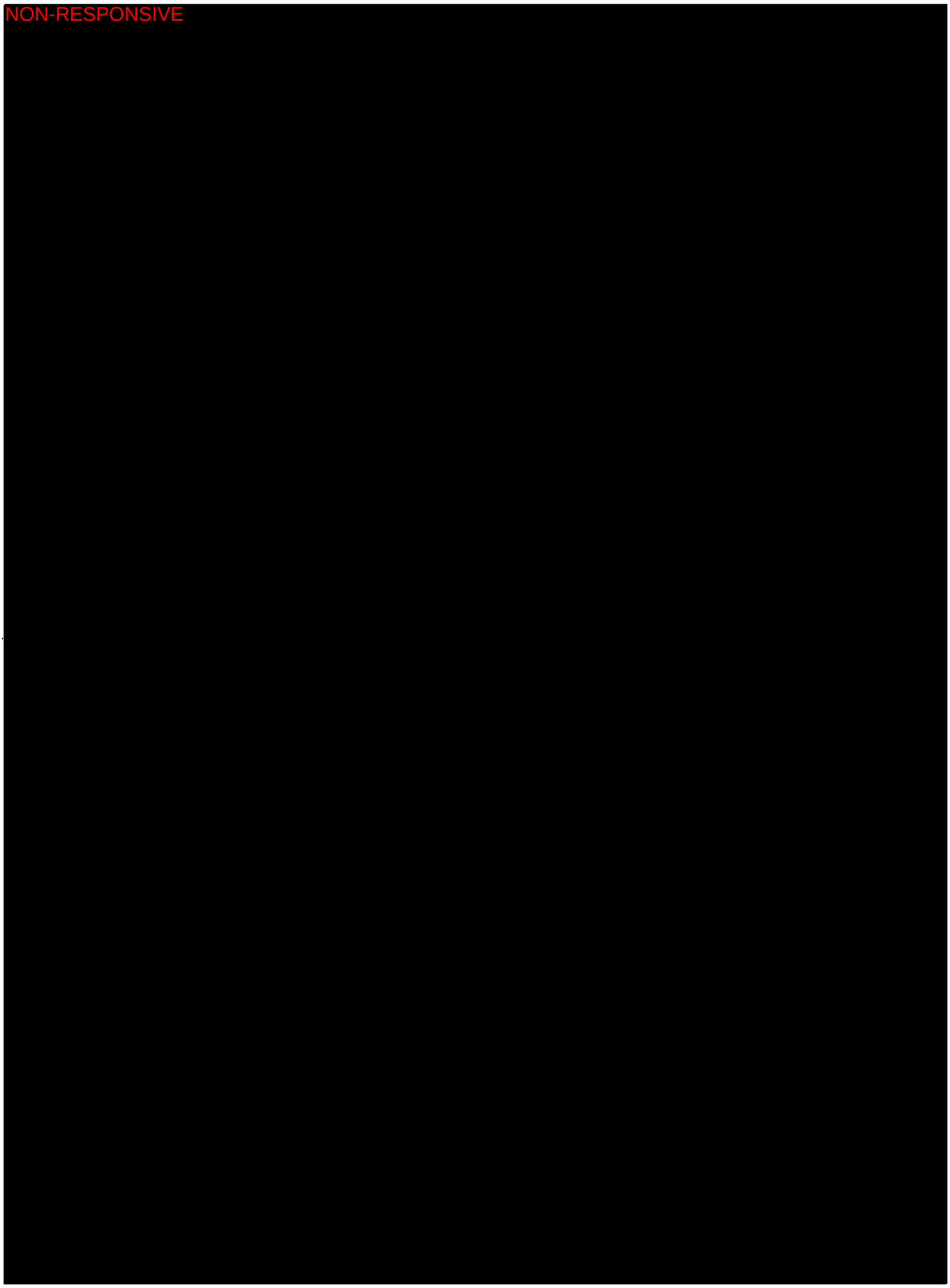

Region 1 was 50 mg/l, ranging from 0 mg/l to 615 mg/l. Three hundred twenty-two water samples (89 percent) from all 8 counties contained iron in excess of the secondary MCL. The mean iron concentration for Region 1 was 1.61 mg/l, ranging from 0.0 mg/l to 8.00 mg/l. Five water samples (1 percent) from 2 of the 8 counties contained sulfate in excess of the secondary MCL. The mean sulfate concentration for Region 1 was 50 mg/l, ranging from 0 mg/l to 295 mg/l. Sixty-seven water samples (18 percent) from 7 of the 8 counties contained total dissolved solids in excess of the secondary MCL. The mean of total dissolved solids was 401 mg/l, ranging from 240 mg/l to 1619 mg/l. In fifty-two water samples (14 percent) from 7 of the 8 counties specific conductance levels exceeded the secondary MCL. The mean specific conductance was 712 umhos/cm, ranging from 405 umhos/cm to 2650 umhos/cm.

Hydraulic Characteristics Of Bedrock Aquifers

Data on the hydraulic characteristics of 248 bedrock wells were available from 114 locations within Region 1 (table 3.14). Mississippian aquifers served most of the locations (66) and supplied the greatest number of bedrock wells (128). Of the eleven bedrock aquifers within the region, the Mississippian Marshall Sandstone served the most locations (25) and supplied the greatest number of wells (40). The Devonian Dundee Limestone served the fewest locations (4) and supplied the least number of wells (5). Well depths in the region ranged from 28 feet in Wayne County to 502 feet in Livingston County.

Eight well capacity values (3 percent) were available for naturally flowing wells and ranged from 1 gpm for the Marshall Sandstone in Lapeer County to 200 gpm for the Marshall in Wayne County. Well capacities for the Pennsylvanian Saginaw Formation ranged from 50 gpm to 610 gpm. The Mississippian Marshall Sandstone ranged from 4 gpm to 505 gpm and the Mississippian Coldwater Shale from 10 gpm to 170 gpm. The Mississippian Berea Sandstone ranged from 2 gpm to 768 gpm, the maximum range within the Mississippian aquifer system. The four Devonian aquifers ranged in well capacity from 2 gpm to 900 gpm; the highest obtained from the Devonian Detroit River Group in Monroe County. Well capacities for Silurian aquifers ranged from 5 gpm to 550 gpm.

Specific capacities for Region 1 ranged from 0.03 gpm/ft for the Berea Sandstone and the undifferentiated Devonian in Washtenaw County to 20 gpm/ft for the Saginaw Formation in Livingston County.

Transmissivities were available only for the Saginaw Formation and Marshall Sandstone, and ranged from 2500 gpd/ft for the Saginaw in Genesee County to 158,100 gpd/ft for the Marshall in Oakland County. Coefficients of storage were available only for the Saginaw Formation and ranged from 3.0×10^{-5} (0.00003) to 1.3×10^{-4} (0.00013) in Genesee County.

TABLE 3.14 - HYDRAULIC CHARACTERISTICS OF THE BEDROCK AQUIFER SYSTEMS, REGION 1 (SOUTHEAST MICHIGAN).

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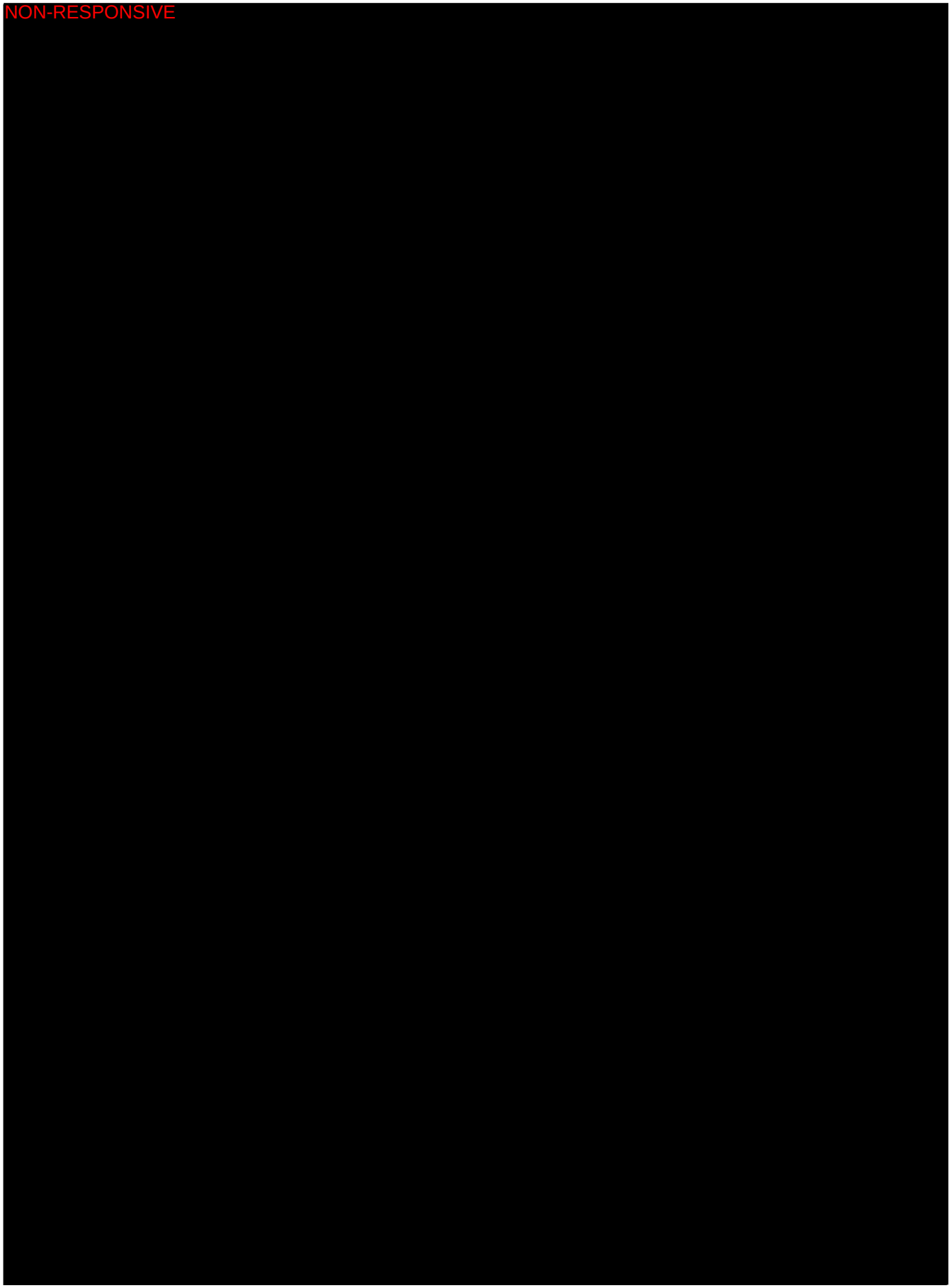


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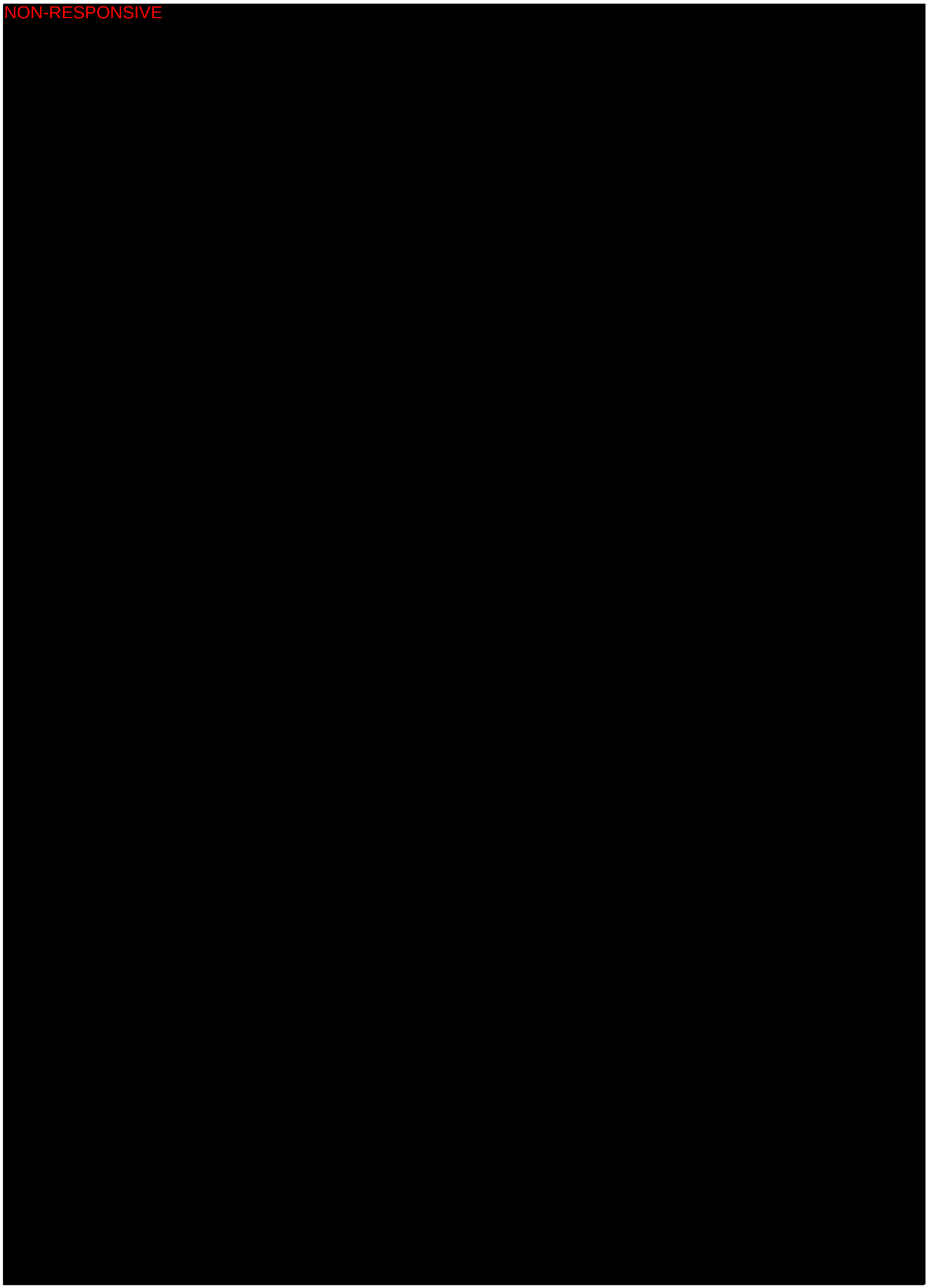
COMMUNITY PUBLIC WATER SUPPLIES



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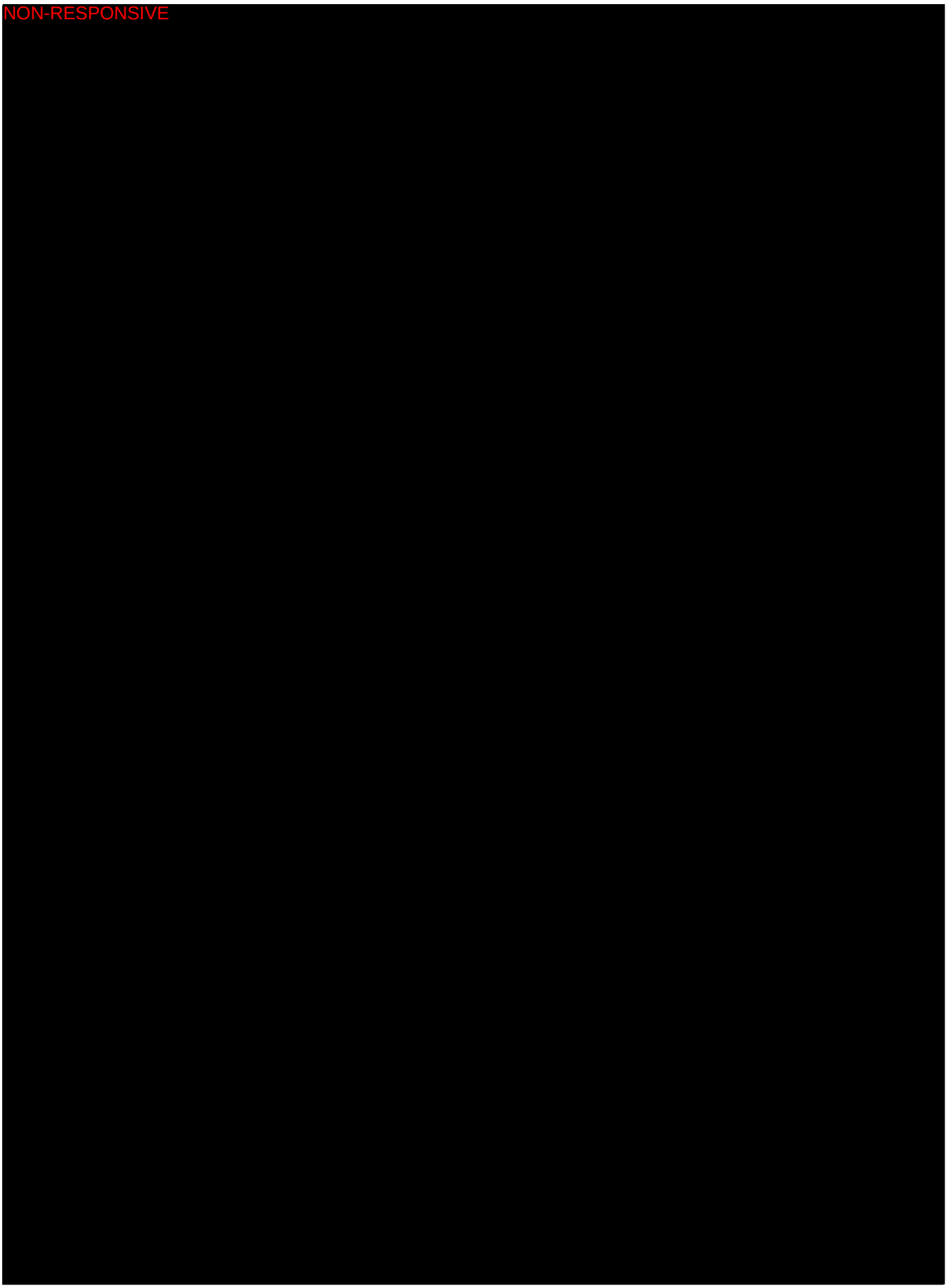

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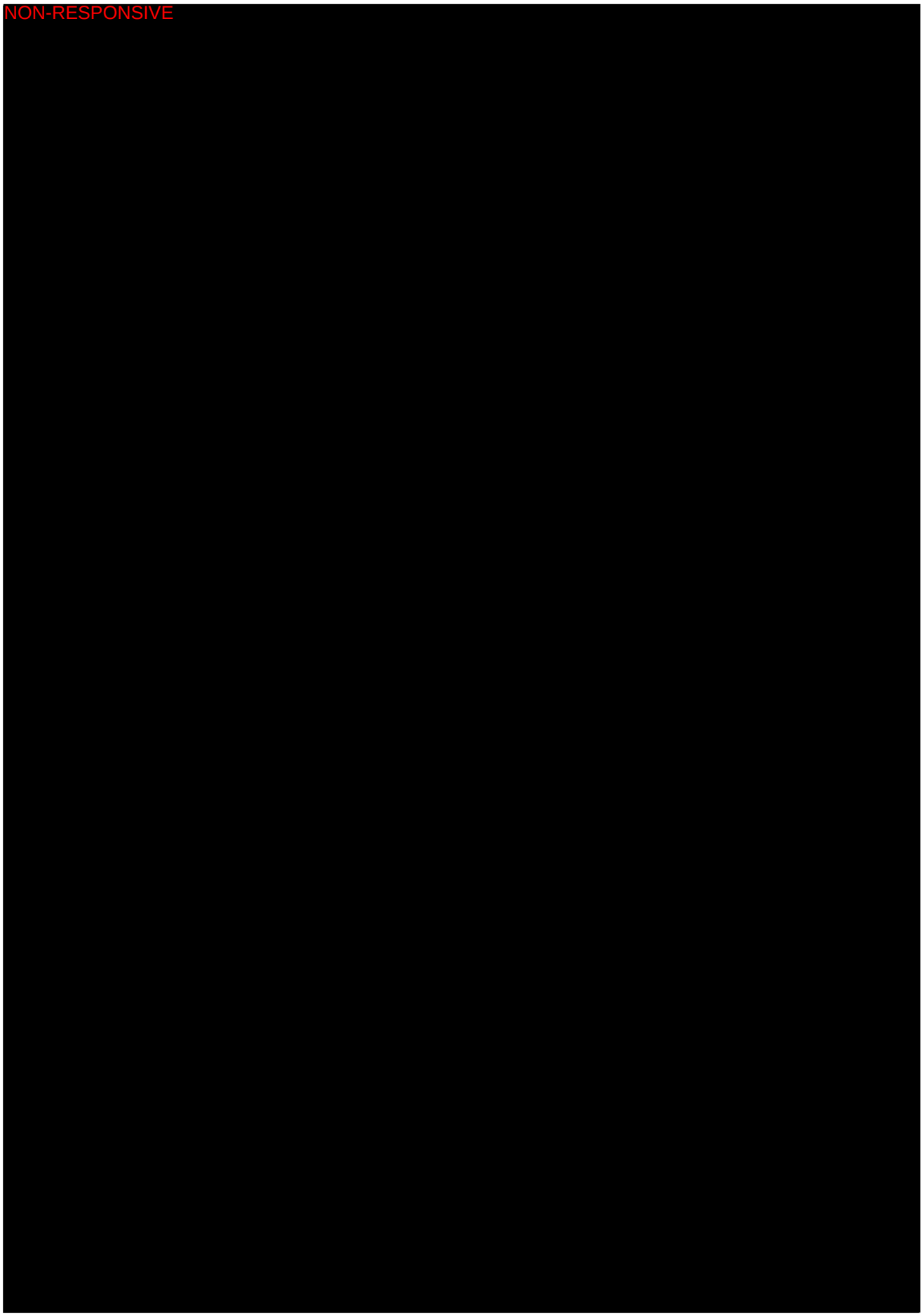

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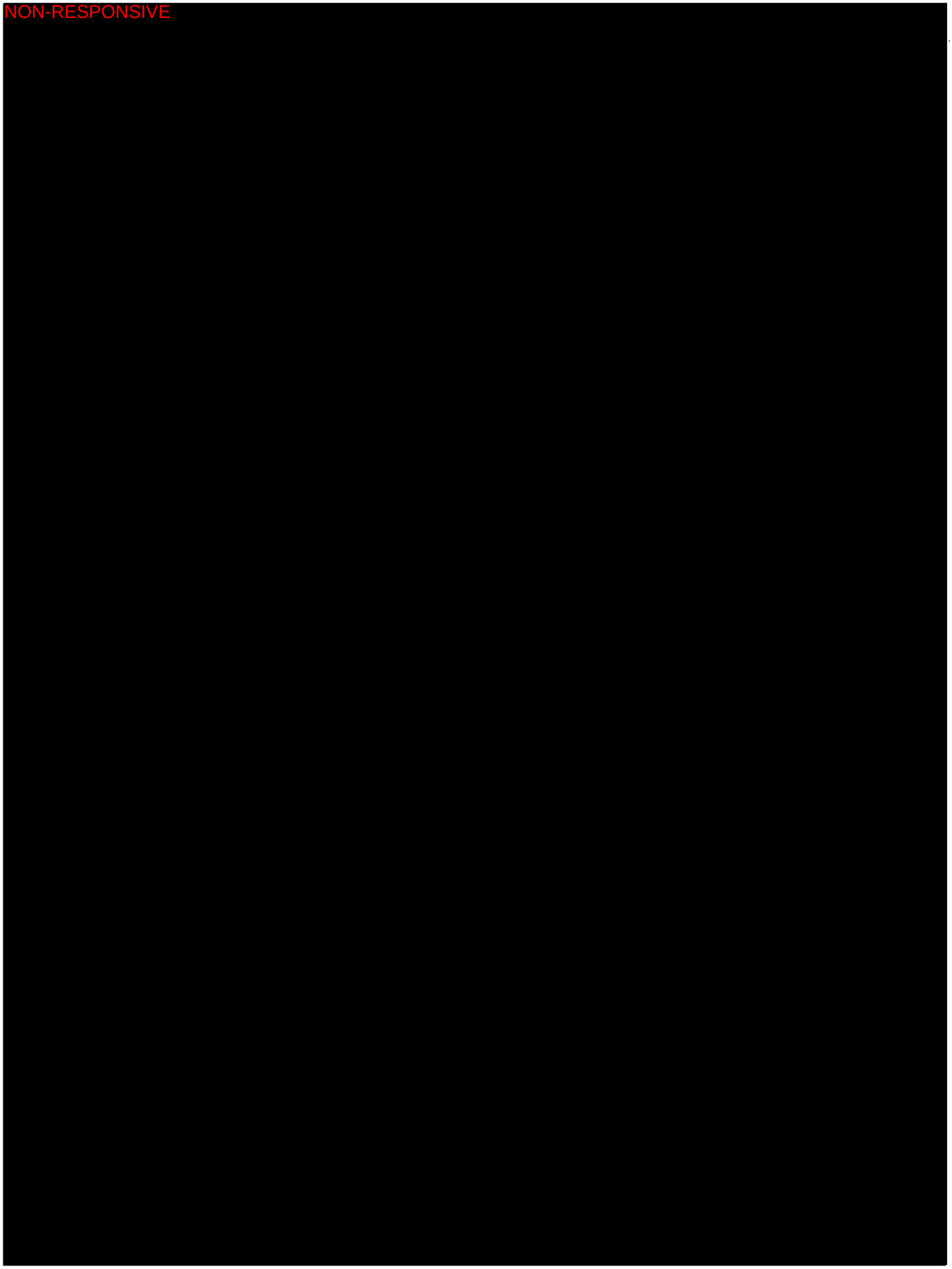

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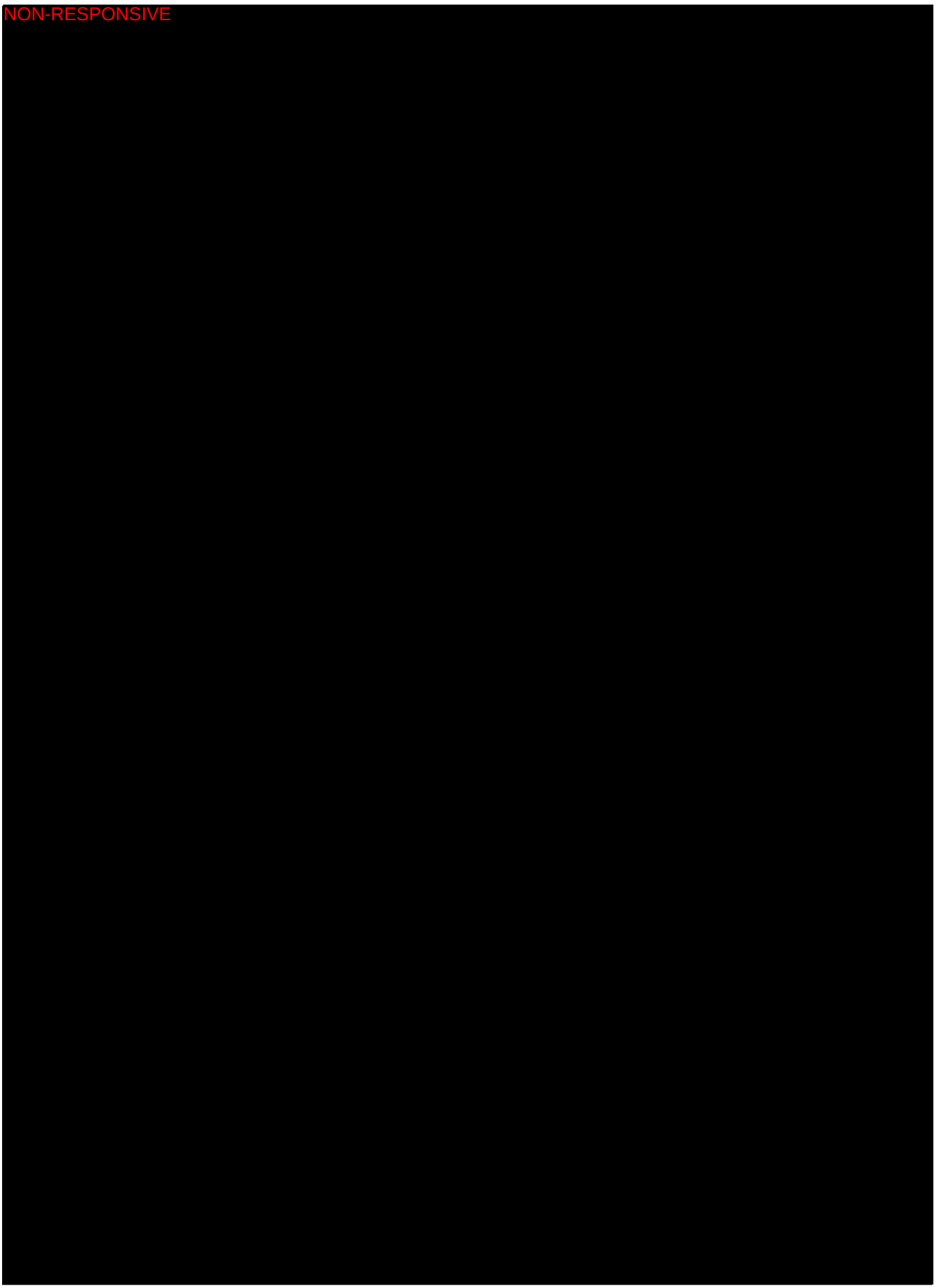

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